



Next-Generation Galaxy Modeling

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What Are the Astrophysical Data Sciences? And Do We Need Them?

$\frac{1}{2} \log \det A$

$\delta(x, y, z)$

$\chi = \exp \left\{ -\frac{1}{2} \sum_{i,j} x_i^T A_{ij} x_j + \sum_i b_i x_i \right\}$

1) let defining line

2) Define $f(x, y, z) = \sum_{i,j} k_{ij}(x_i, y_j)$

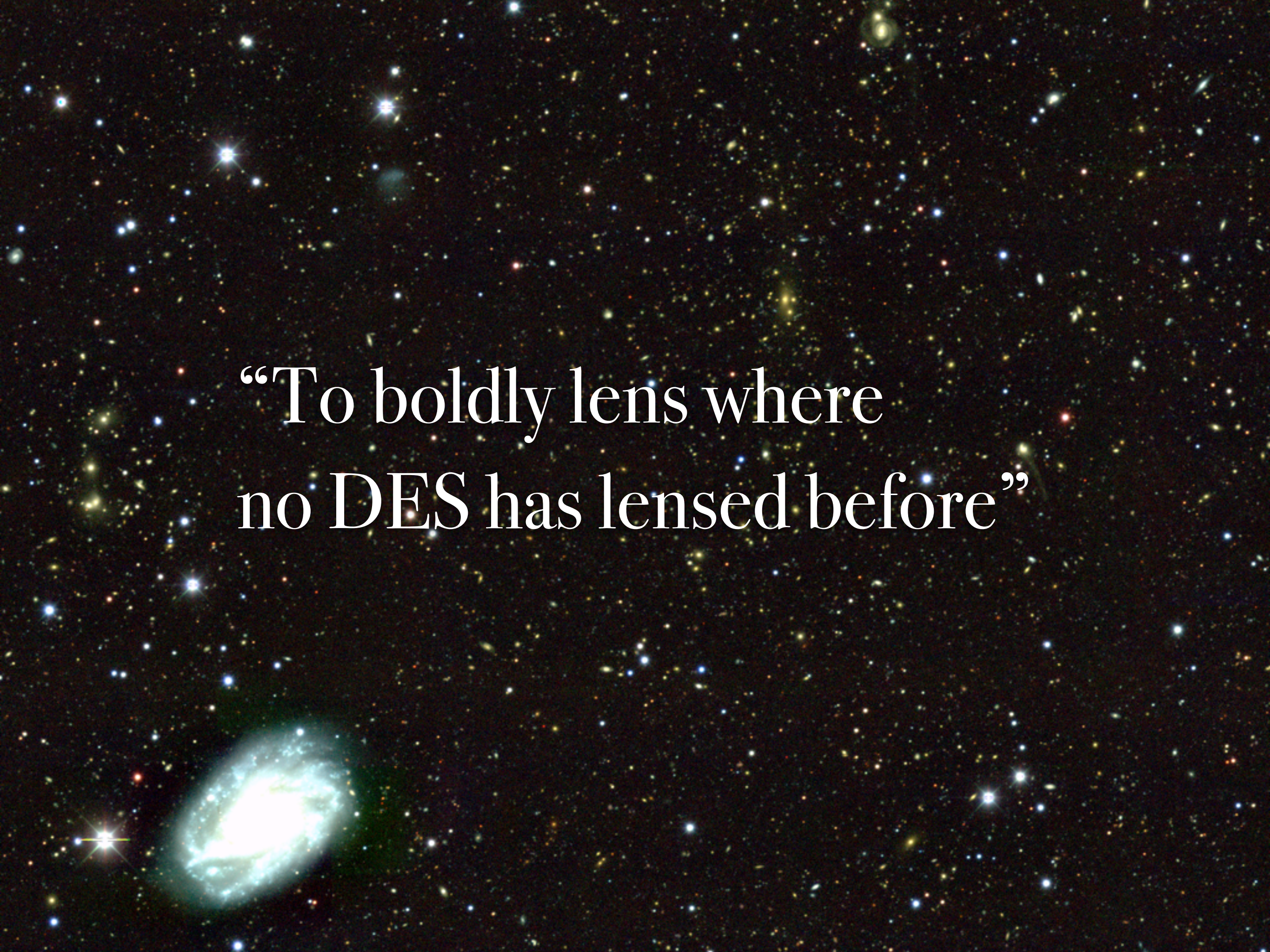
$p(x|y) = p(x|z) p(z|y)$

$p(x|y) = \int p(x|z) p(z|y) dz$

all go

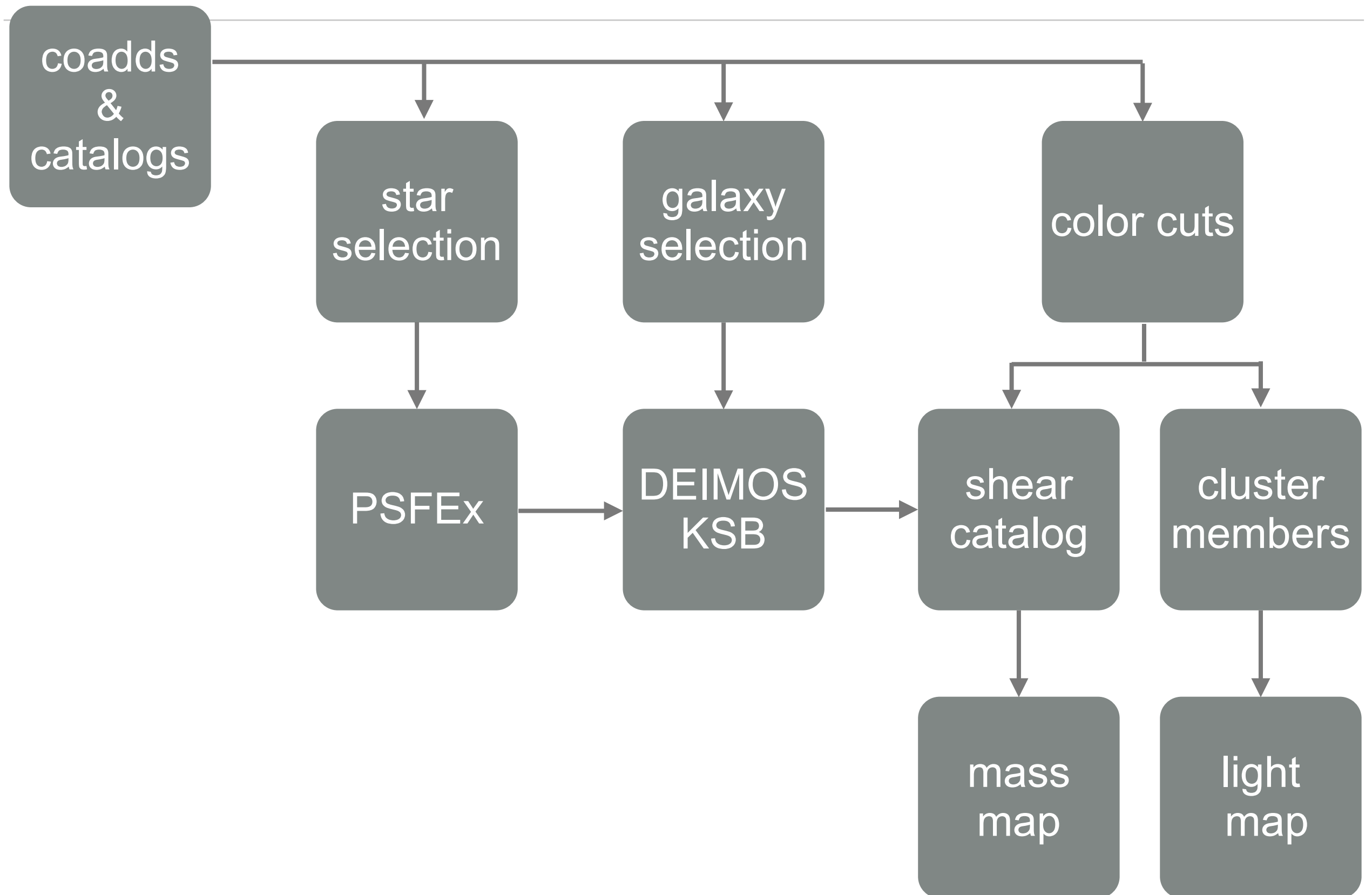
$p(x|y) = \int p(x|z) p(z|y) dz$



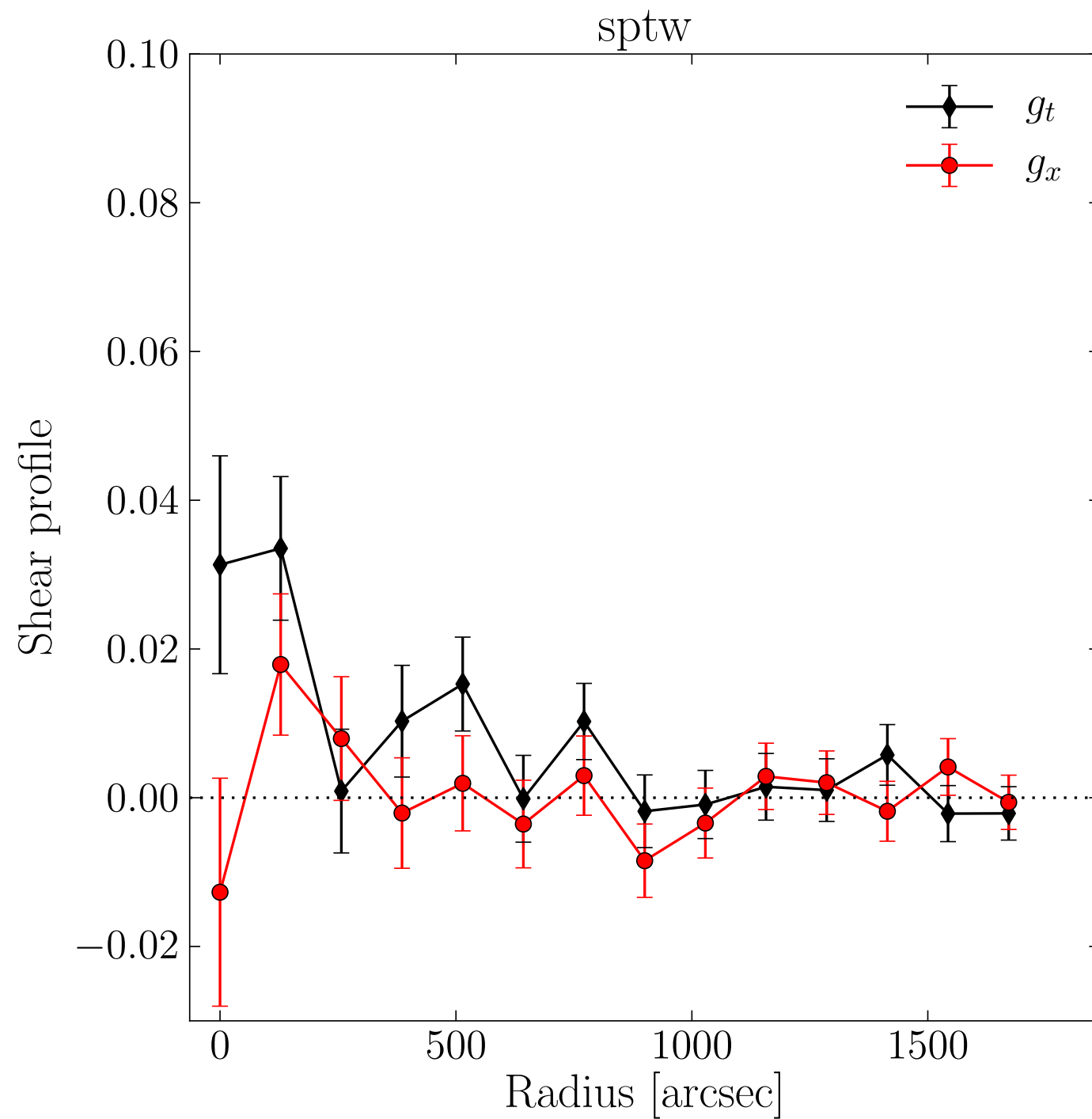


“To boldly lens where
no DES has lensed before”

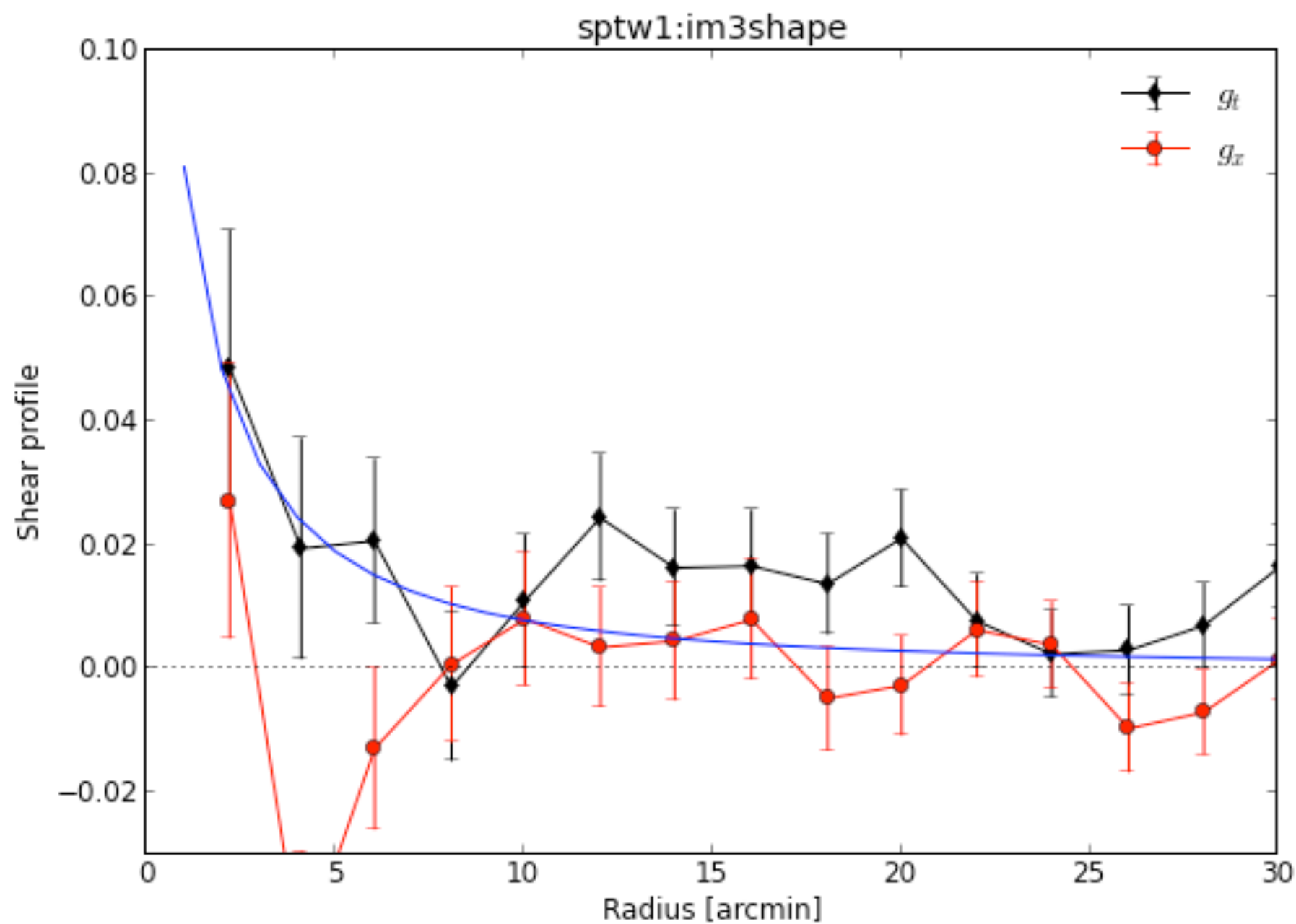
The Master Plan



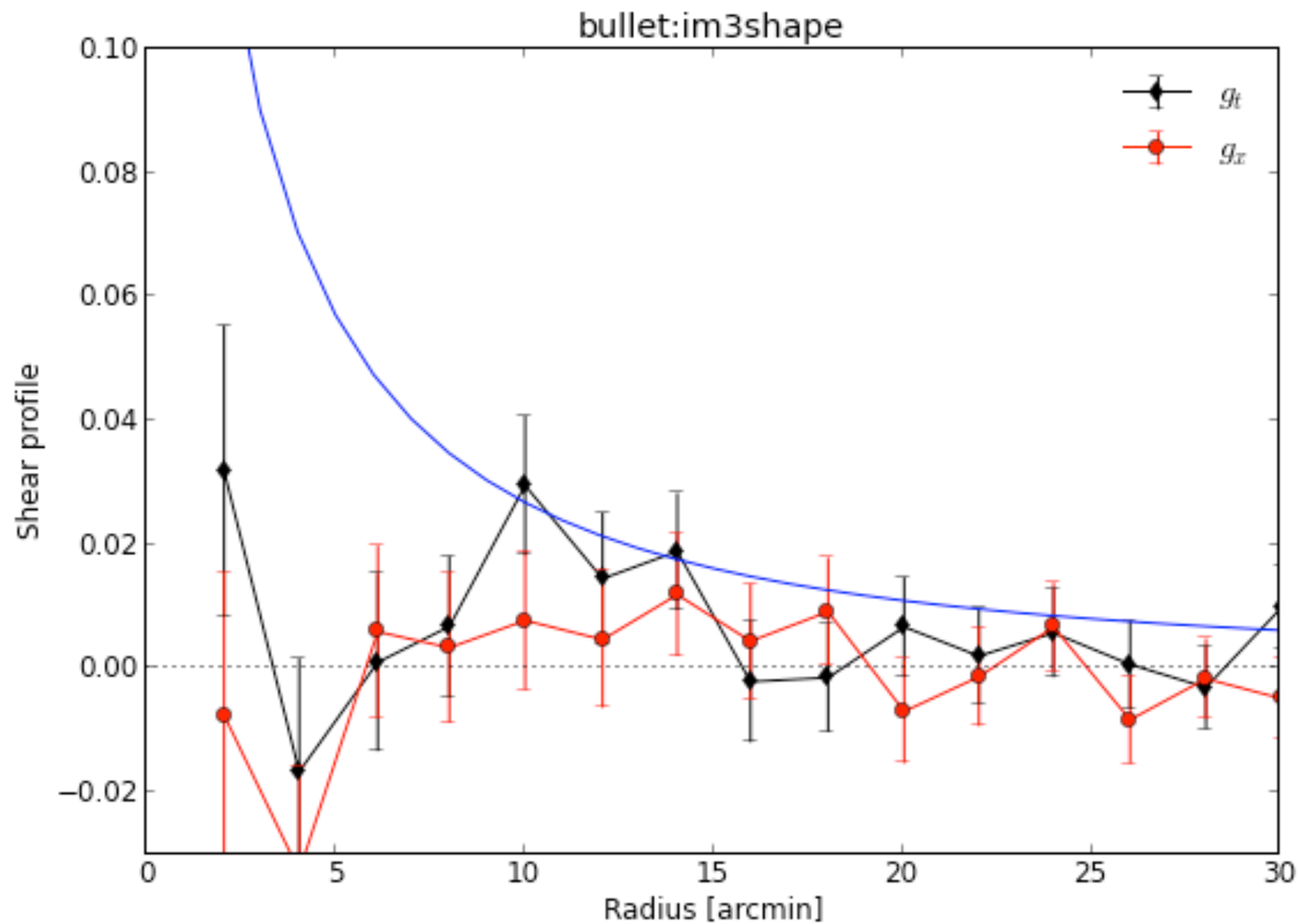
Result After Busy Week



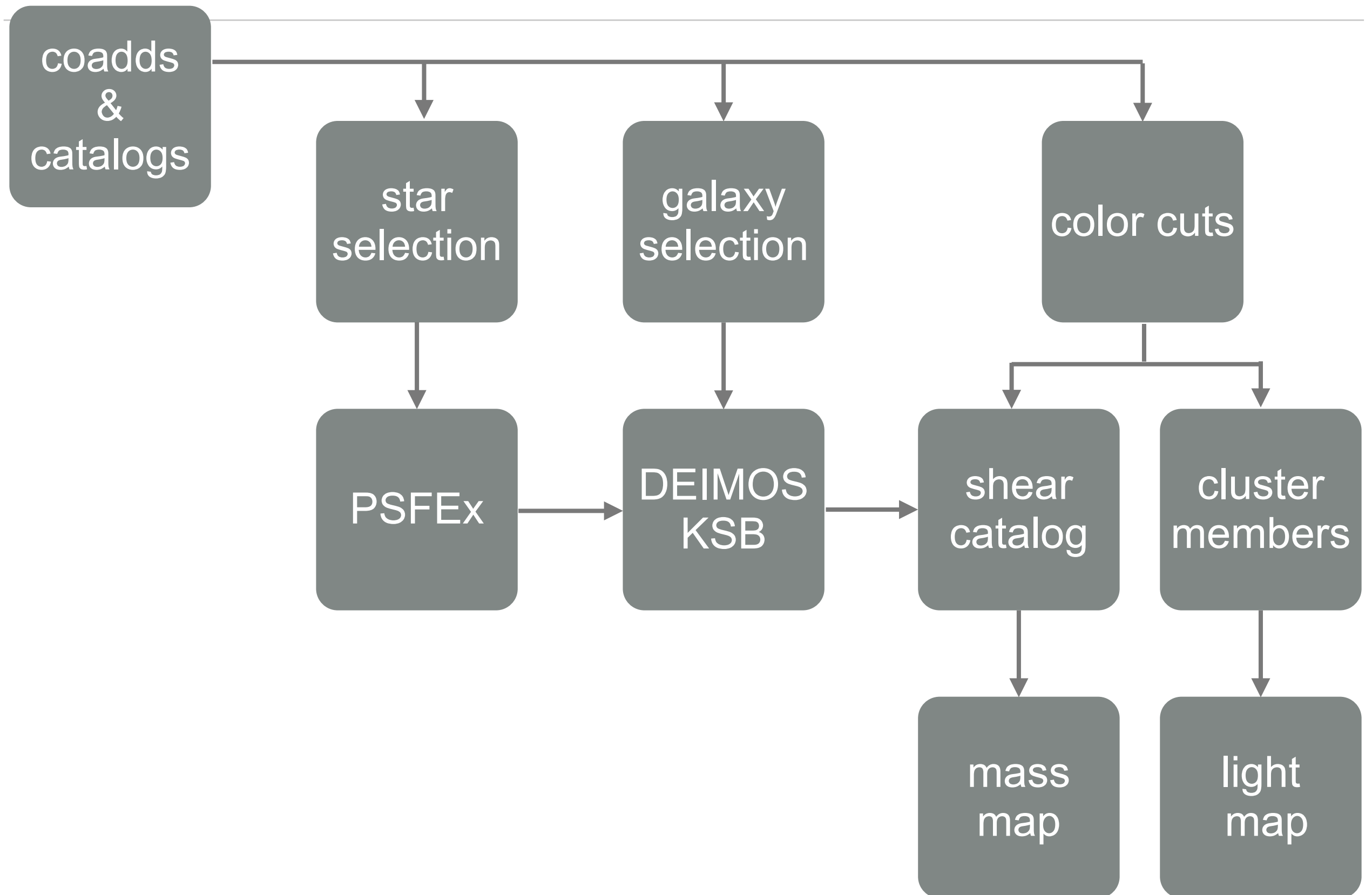
Result After 3 Months (April 2013)



Result After 3 Months (April 2013)



The Master Plan: 😐😓😡&\$!#%





arXiv.org > astro-ph > astro-ph.CO

Cosmology and Nongalactic Astrophysics

Authors and titles for recent submissions

- Mon, 19 May 2014
- Fri, 16 May 2014
- Thu, 15 May 2014
- Wed, 14 May 2014
- Tue, 13 May 2014

[total of 76 entries: 1-25 | 26-50 | 51-75 | 76]
 [showing 25 entries per page: fewer | more | all]

Mon, 19 May 2014

[1] [arXiv:1405.4285](#) [pdf, other]

Mass and galaxy distributions of four massive galaxy clusters from Dark Energy

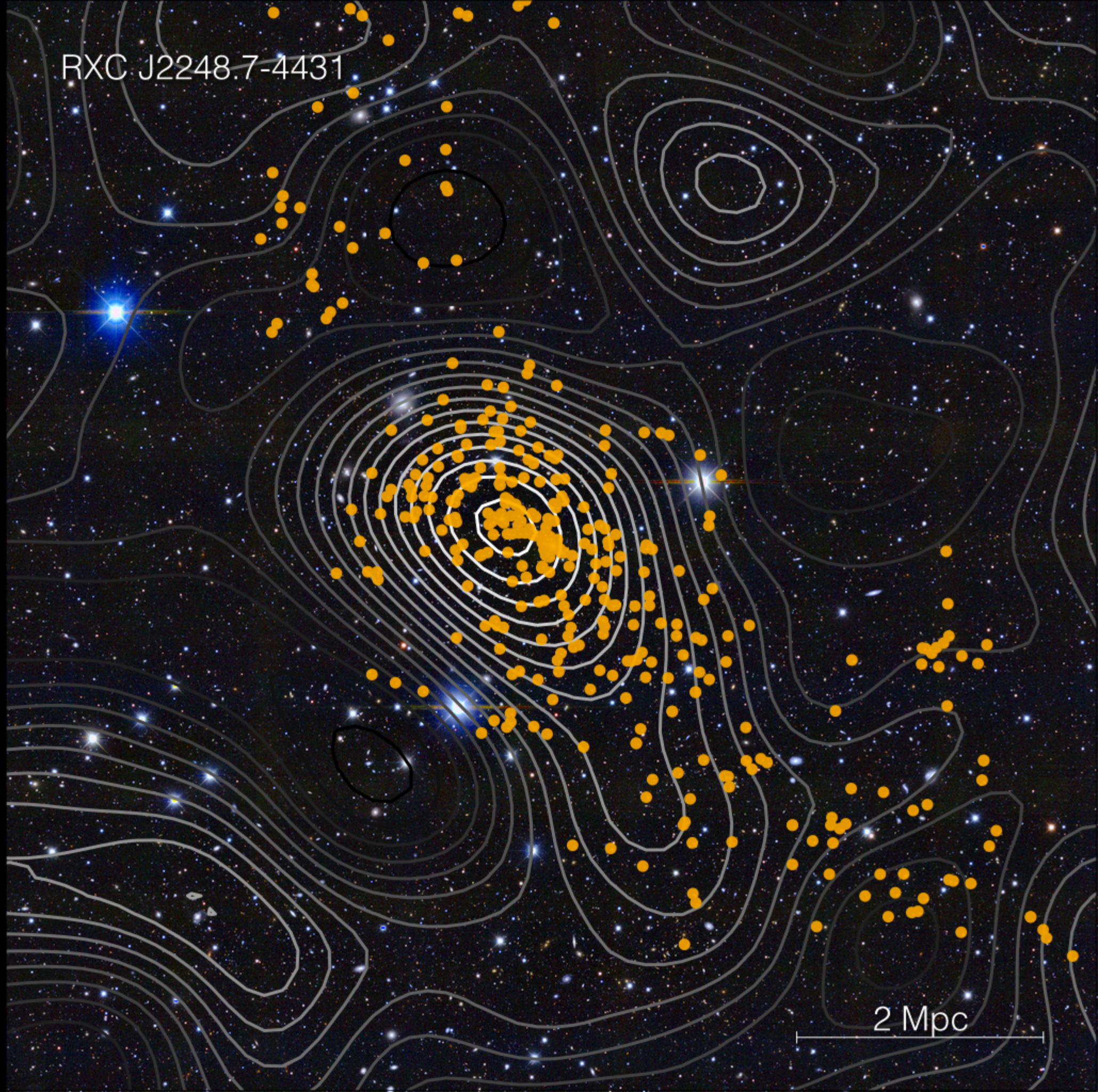
Survey Science Verification data

P. Melchior, E. Suchyta, E. Huff, M. Hirsch, T. Kacprzak, E. Rykoff, D. Gruen, R. Armstrong, D. Bacon, K. Bechtol, G. M. Bernstein, S. Bridle, J. Clampitt, K. Honscheid, B. Jain, S. Jouvel, E. Krause, H. Lin, N. MacCrann, K. Patton, A. Plaza, B. Rowe, V. Vikram, H. Wilcox, J. Young, J. Zuntz, T. Abbott, F. Abdalla, S. S. Allam, M. Banerji, J. P. Bernstein, R. A. Bernstein, E. Berlin, E. Buckley-Geer, D. L. Burke, F. J. Castander, L. N. da Costa, C. E. Cunha, D. L. Depoy, S. Desai, H. T. Diehl, P. Doi, J. Estrada, E. Evrard, A. Fausti Neto, E. Fernandez, D. A. Finley, B. Flaugher, J. A. Frieman, Gaztanaga, D. Gerdes, R. A. Gruendl, G. R. Gutierrez, M. Jarvis, I. K. Kuehn, H. Kuropatkin, O. Lahav, M. A. G. Maia, M. Makler, Marshall, K. W. Merritt, et al. (28 additional authors not shown)
 Comments: 19 pages, 10 figures; high-resolution version
 URL
 Subjects: Cosmology and Nongalactic Astrophysics (astro-ph.CO)

[2] [arXiv:1405.4130](#)

Statistical

RXC J2248.7-4431

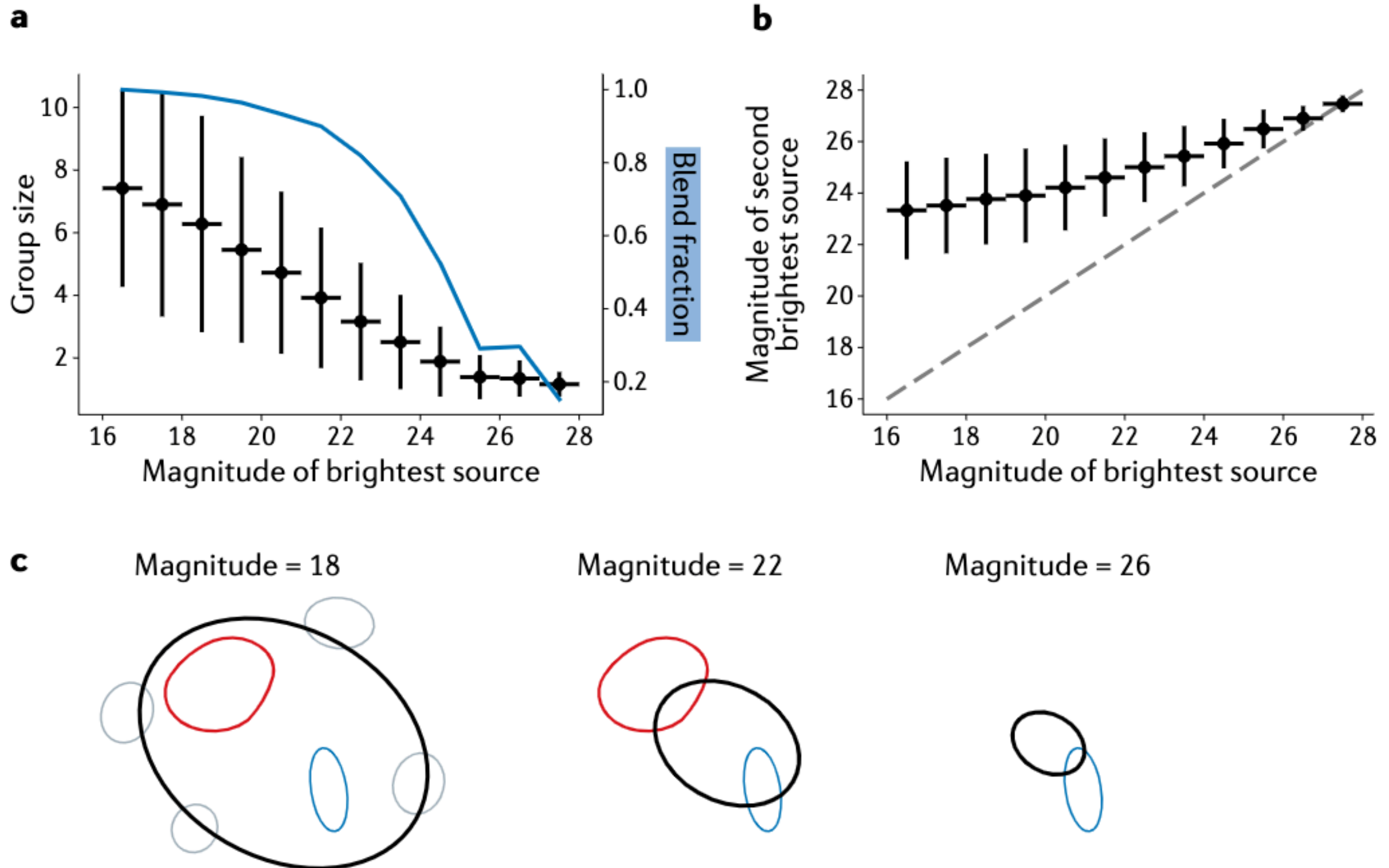


2 Mpc

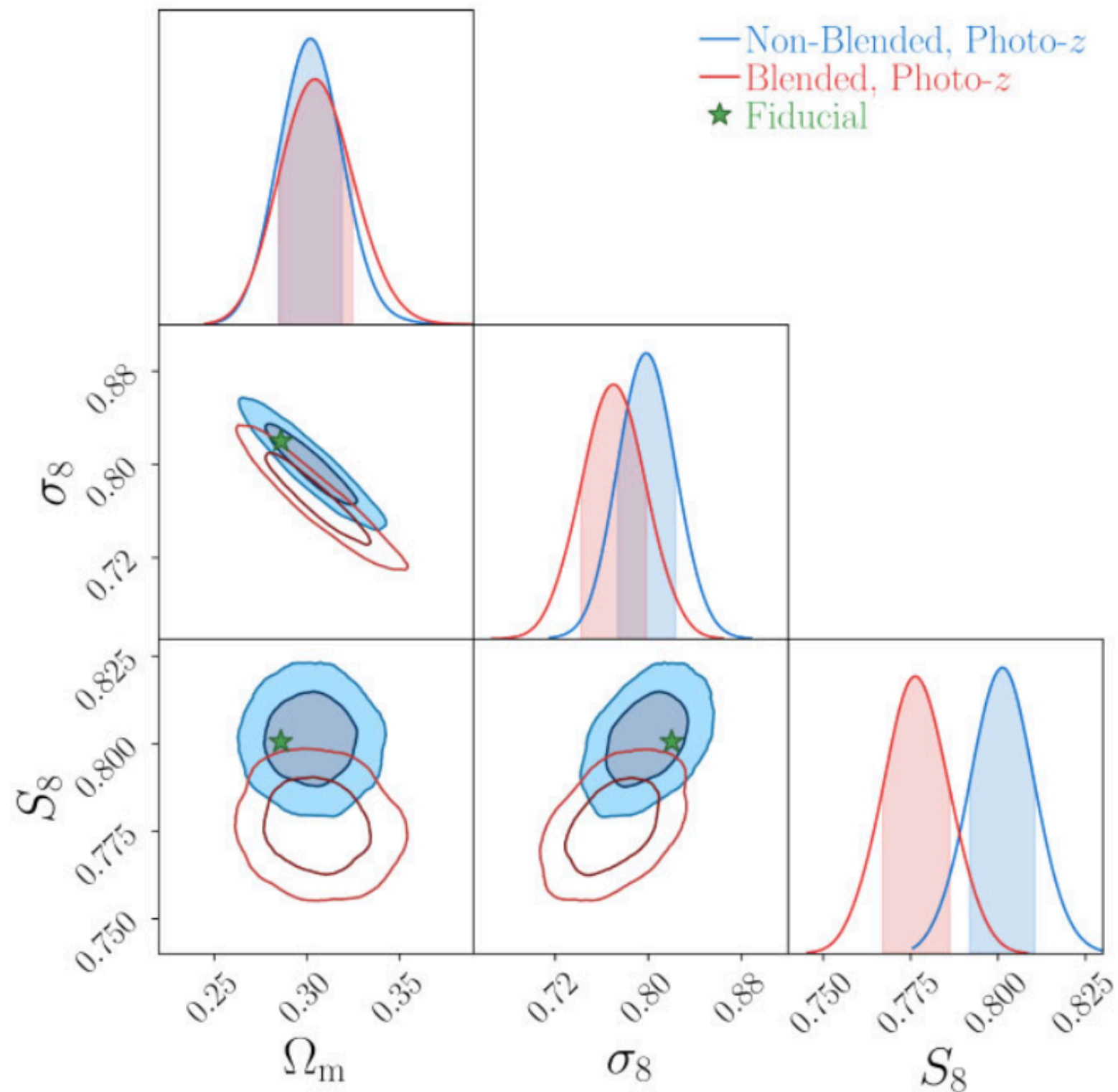
Abundance: The New Normal

A Prevalent Problem

Melchior et al. (2021)
Nature Physics Review, 3, 712



We're Paying a Price

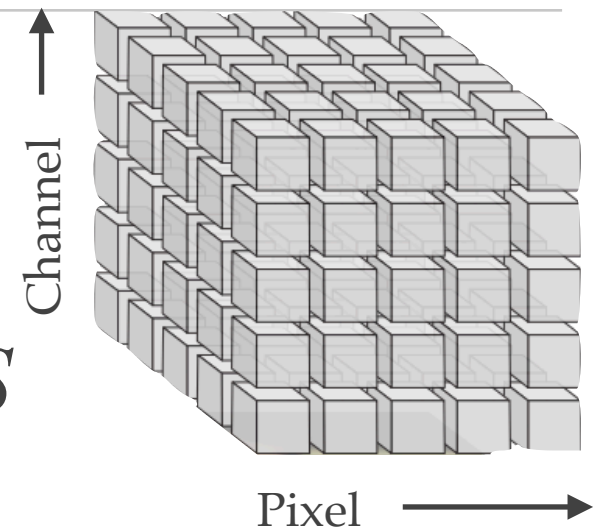


From Nourbakhsh et al. (2022)

Hyperspectral Model of the Sky

$$\text{Scene} = \sum_k \text{Spectrum}_k \times \text{Morphology}_k = A \cdot S$$

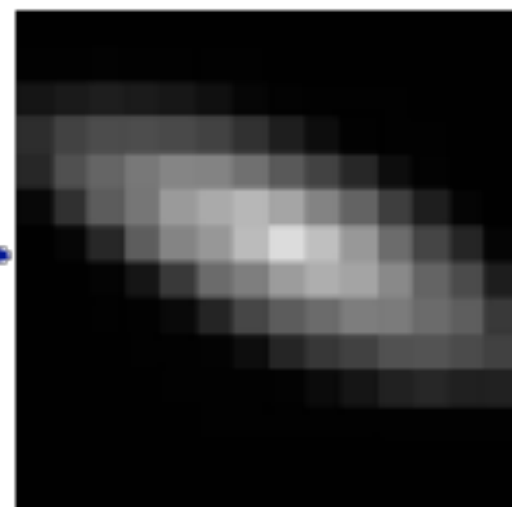
❖ Rendering / Forward Operators: $A \cdot S \rightarrow P \cdot A \cdot S$



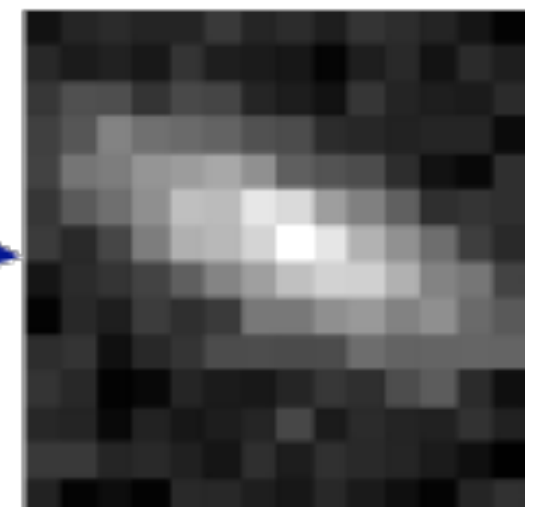
original



convolved



pixellated



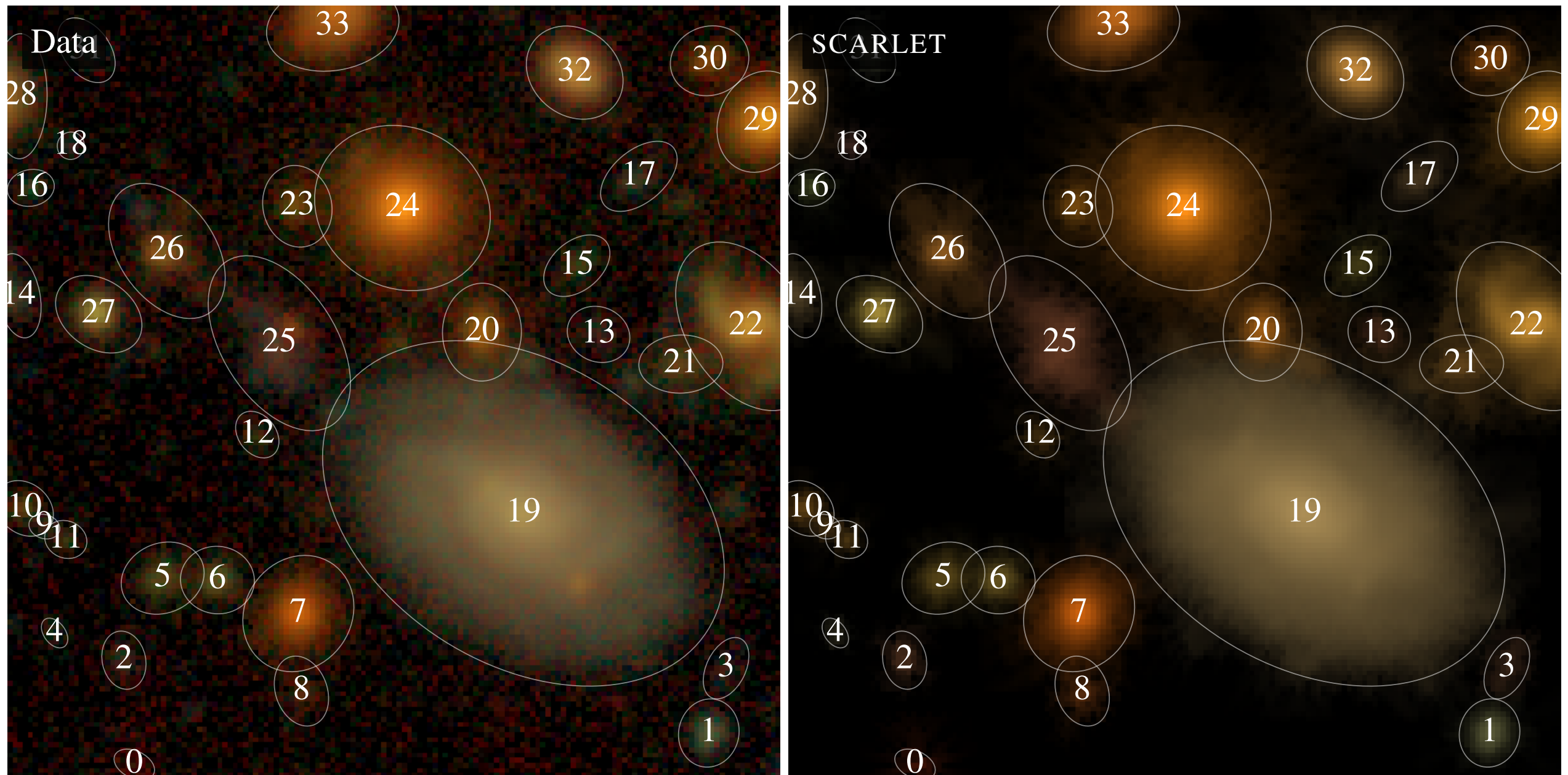
noisy

❖ Probabilistic model: $p(Y | A, S; P) \propto -\frac{1}{2} \|Y - P \cdot A \cdot S\|_2^2$

Scarlet

Melchior et al. (2018)
A&C, 24, 129

code: <http://github.com/pmelchior/scarlet>

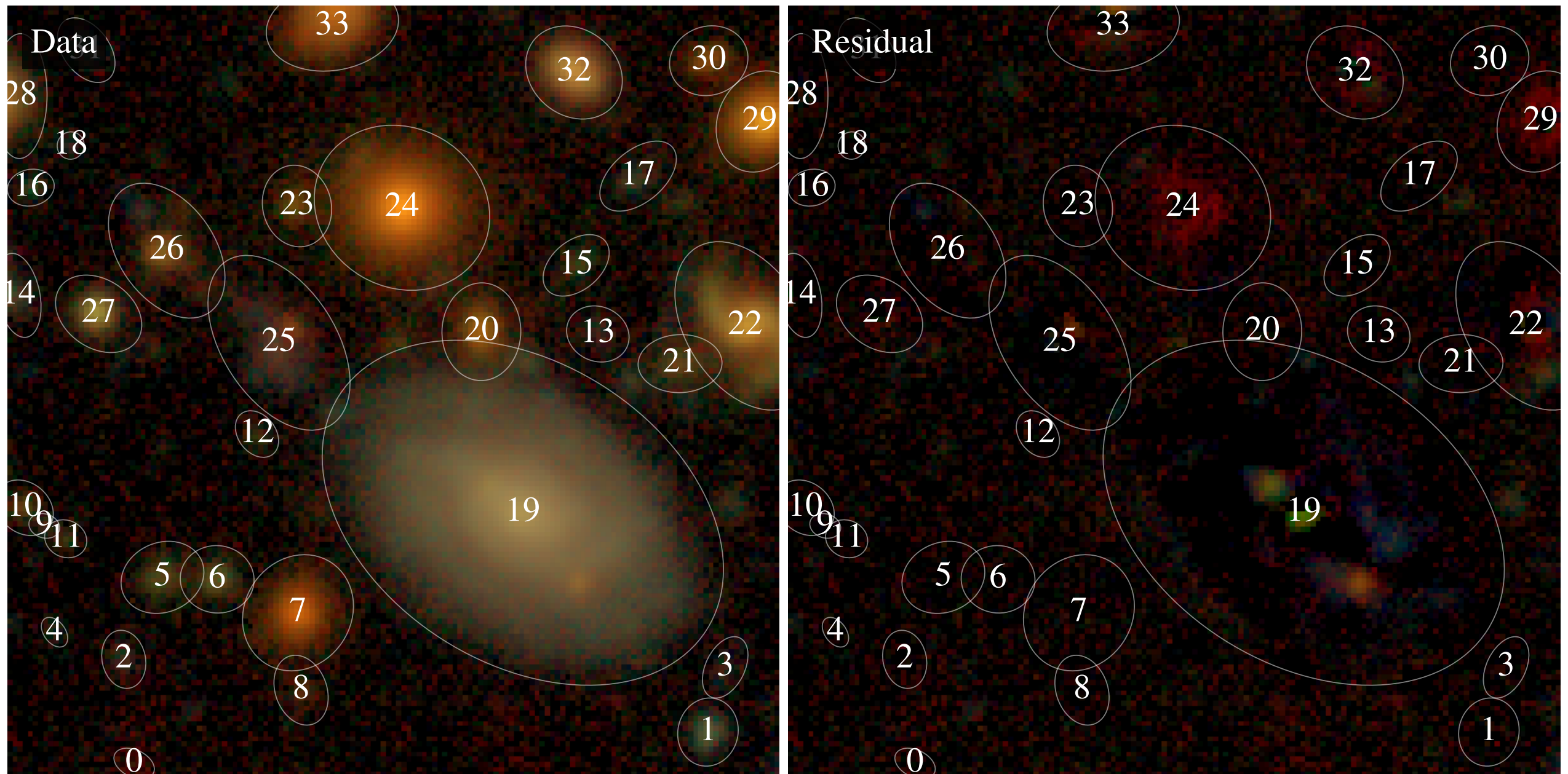


5-band HSC

Scarlet

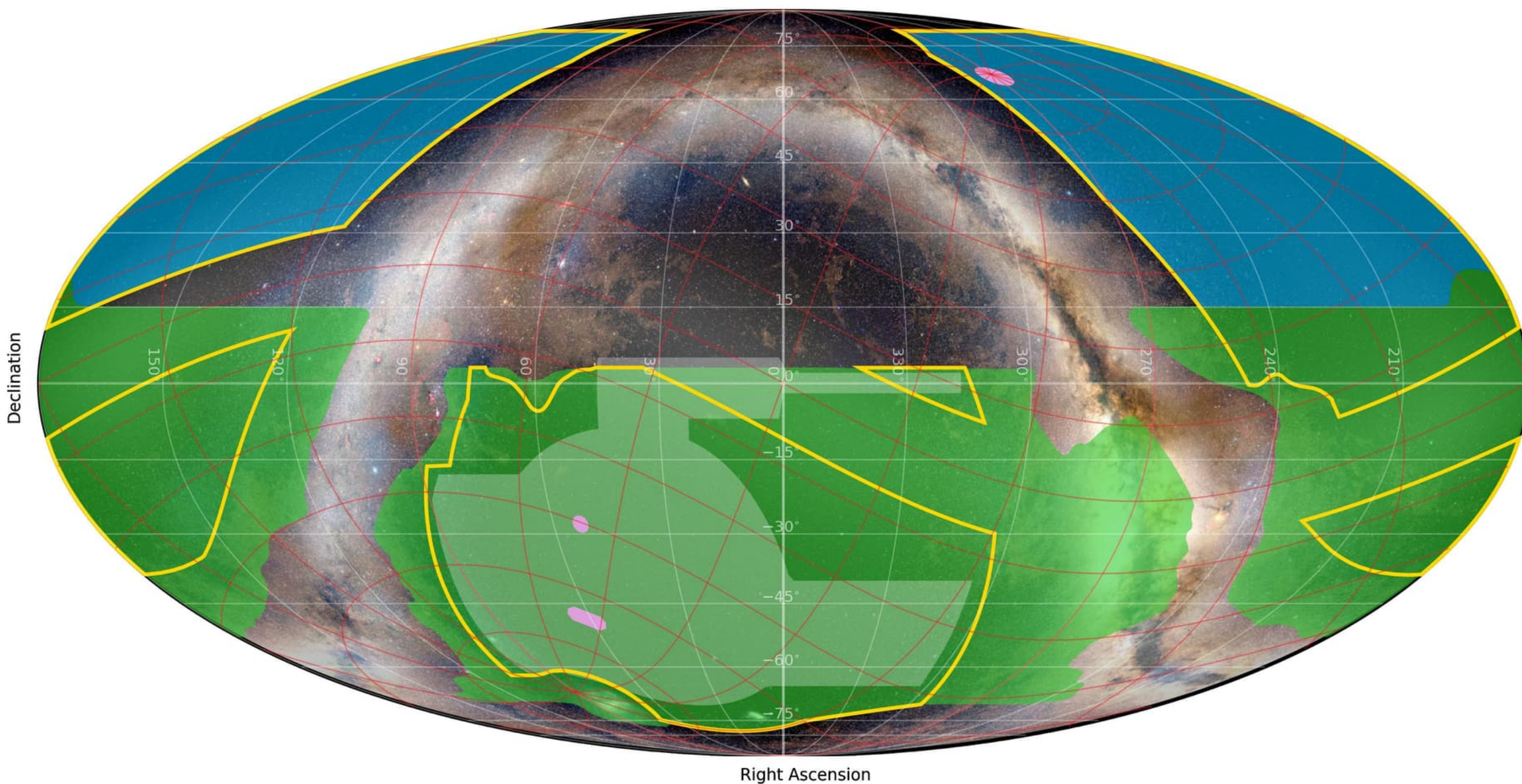
Melchior et al. (2018)
A&C, 24, 129

code: <http://github.com/pmelchior/scarlet>



5-band HSC

The New Era



Ground-based coverage of the 16 Kdeg² Euclid Wide Survey Region of Interest [origin/bands/overlap/calendar] [Mollweide Celestial]

■ LSST Wide-Fast-Deep (Rubin), ugriz : 10.3 Kdeg² overlap by 2026

■ UNIONS (CFHT/Pan-STARRS/Subaru), ugriz : 5.9 Kdeg² overlap by 2026

■ DES (Blanco), griz : 4.5 Kdeg² overlap since 2019

□ Euclid Region of Interest : 16.2 Kdeg²

■ Euclid Deep Fields [53 deg²]

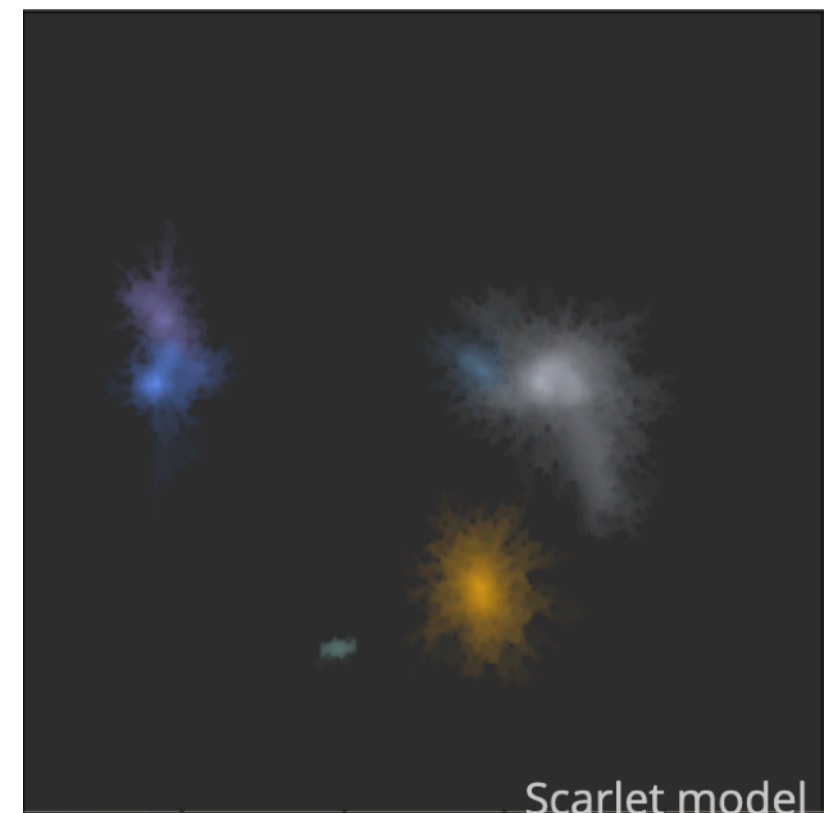
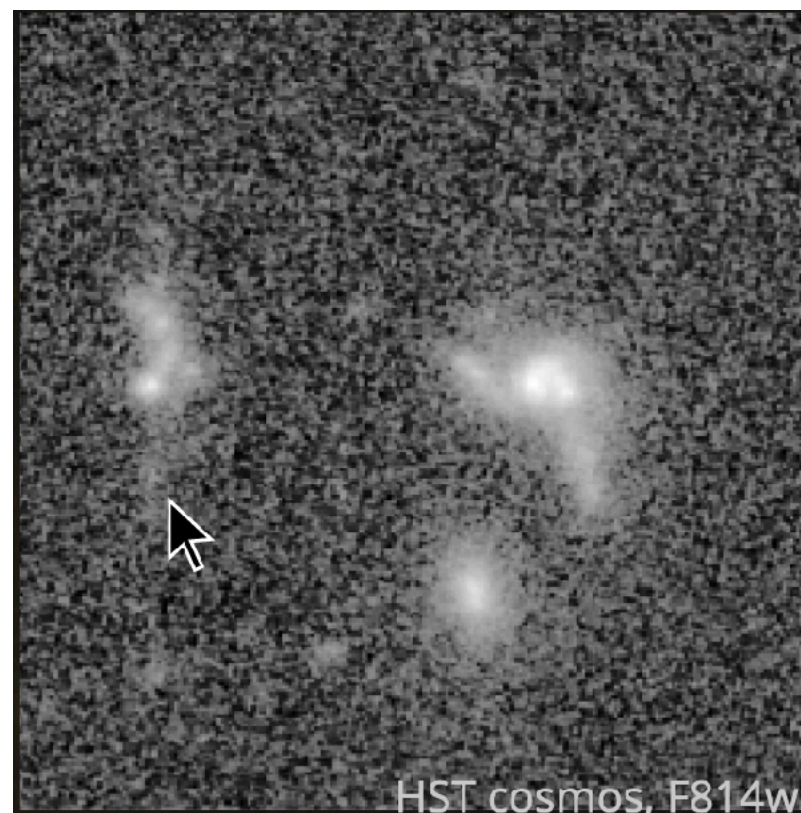
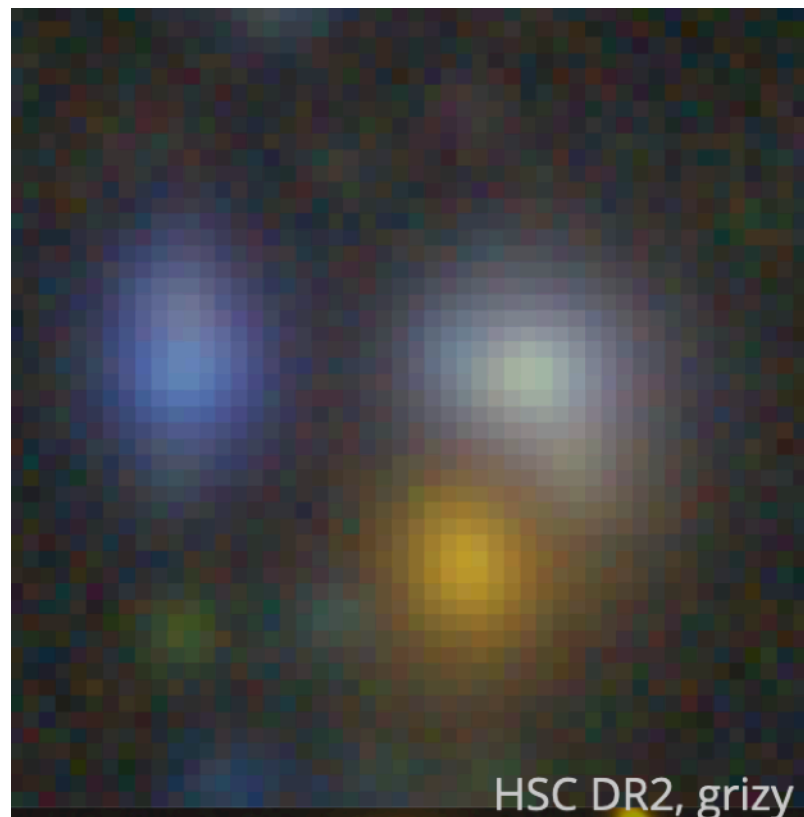


Background image: Euclid Consortium / Planck Collaboration / A. Mellinger

Multiple Instruments

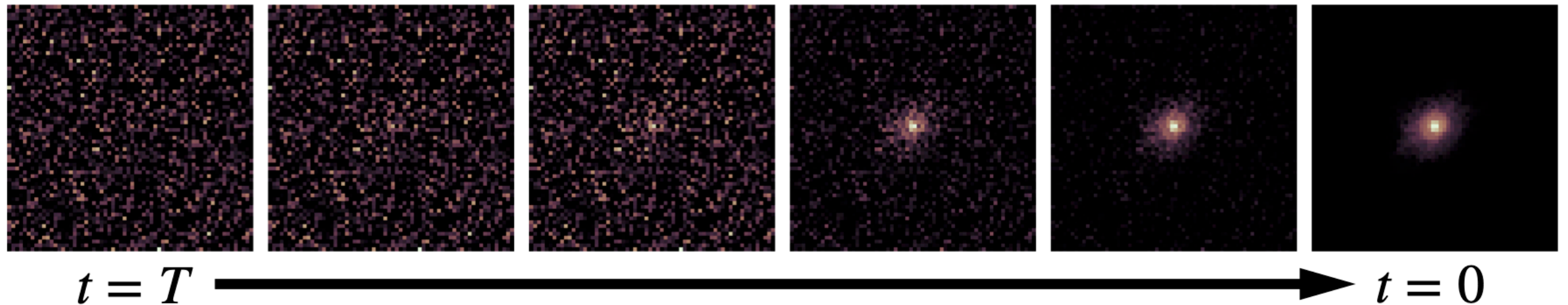
Joseph, Melchior, Moolekamp (2021)
arXiv:2107.06984

- ❖ Independent observations: $\sum_l \|Y_l - \Delta P_l \cdot A \cdot S\|_2^2$
- ❖ Requires matching of resolution, PSF, wavelength coverage
- ❖ Defines common spatial and spectral frame for joint model



Neural Network Priors

Sampson et al. (2024)
A&C, 49, 100875



- ❖ Represents prior over galaxy morphologies $p(S_k)$
- ❖ Jointly optimize the posterior (Lanusse, PM, Moolekamp, 2019)

$$\log p(Y | A, S; P) \sum_k \log p(S_k)$$

- ❖ Now: Denoising Diffusion Model

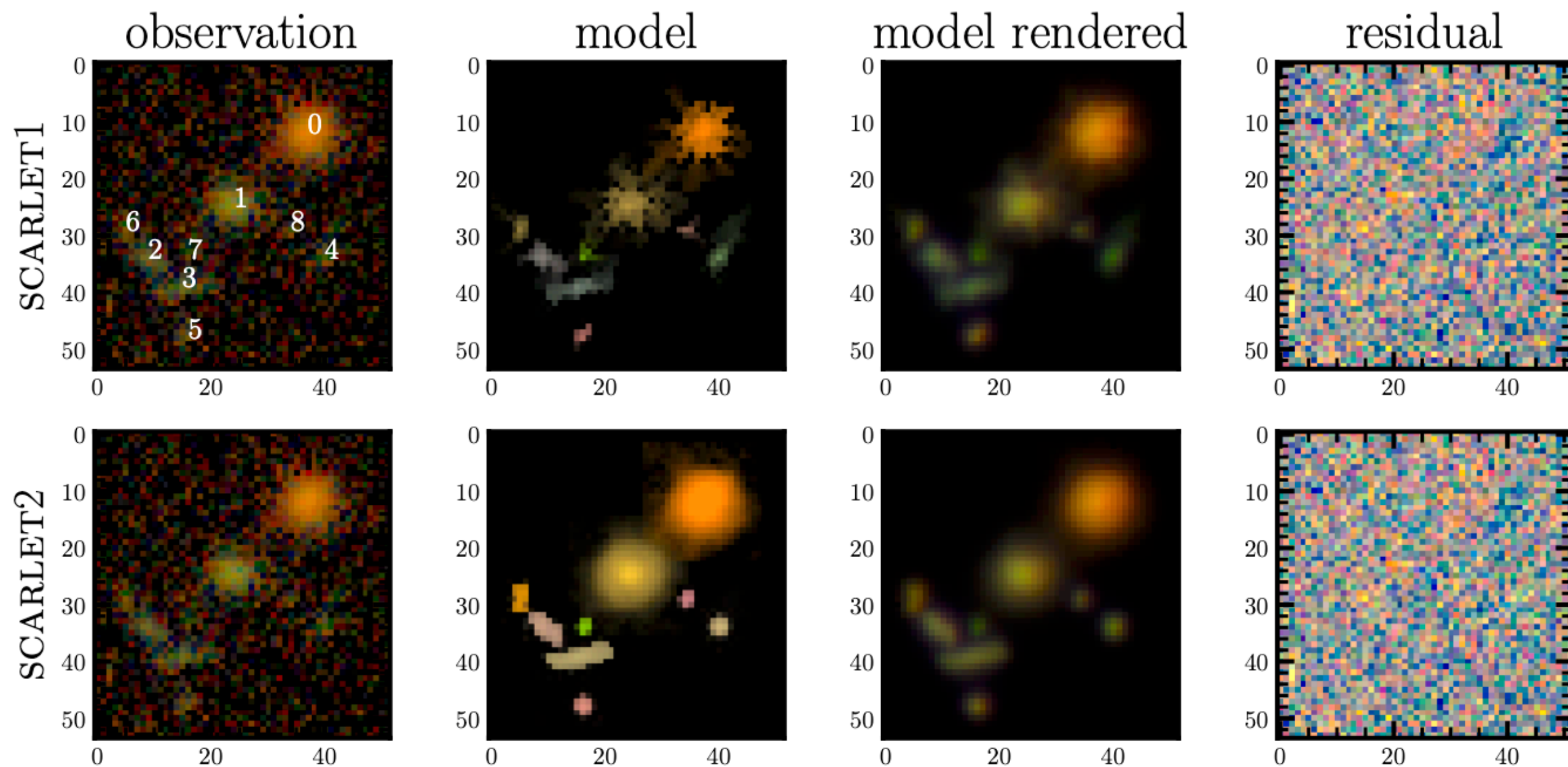
$$\nabla \log p(Y | A, S; P) + \sum_k \nabla \log p(S_k)$$



Matt Sampson

The Effects of Priors

Sampson et al. (2024)
A&C, 49, 100875

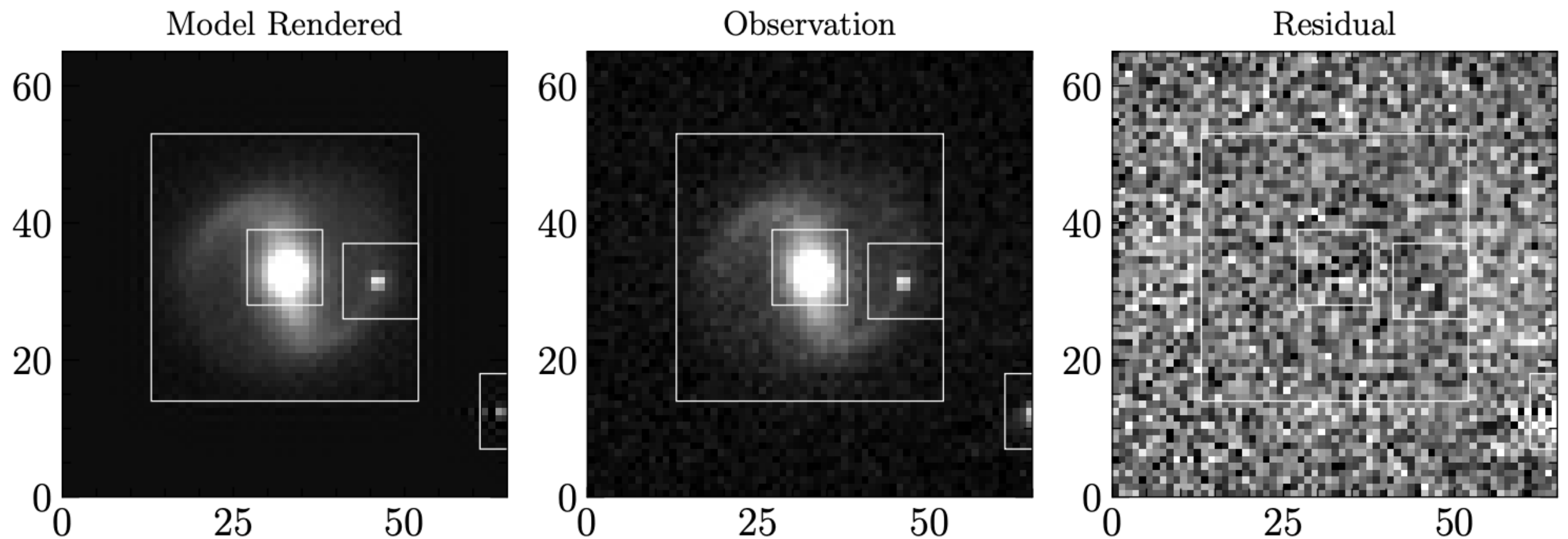


Transient Models



Charlotte Ward

- ❖ Static Source: enforce $A_{k,t} = A_k$ for $t = 1, 2, \dots$
- ❖ Point Source plus Static Extended Source:



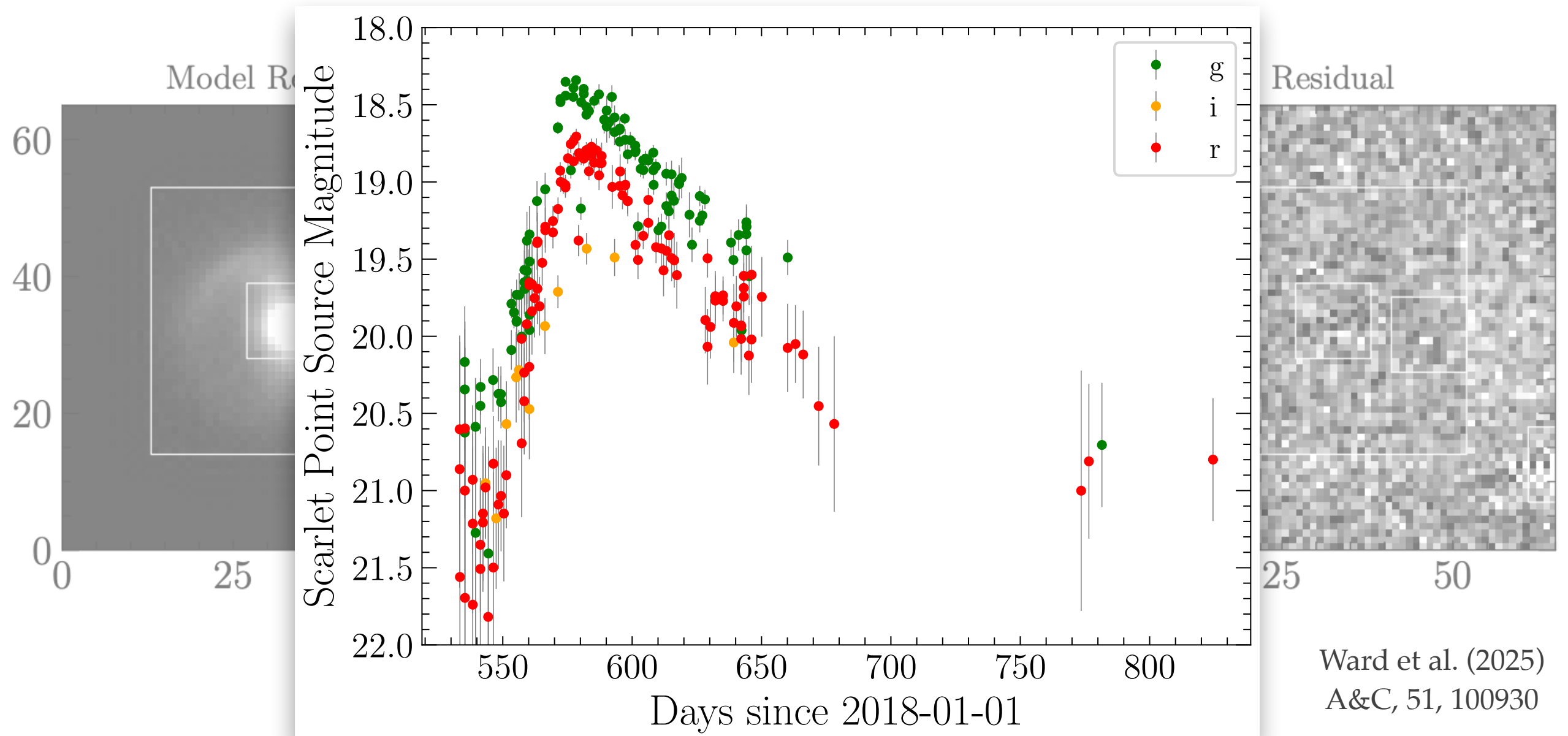
(a) ZTF19abzrhgq

Transient Models



Charlotte Ward

- ❖ Static Source: enforce $A_{k,t} = A_k$ for $t = 1, 2, \dots$
- ❖ Point Source plus Static Extended Source:



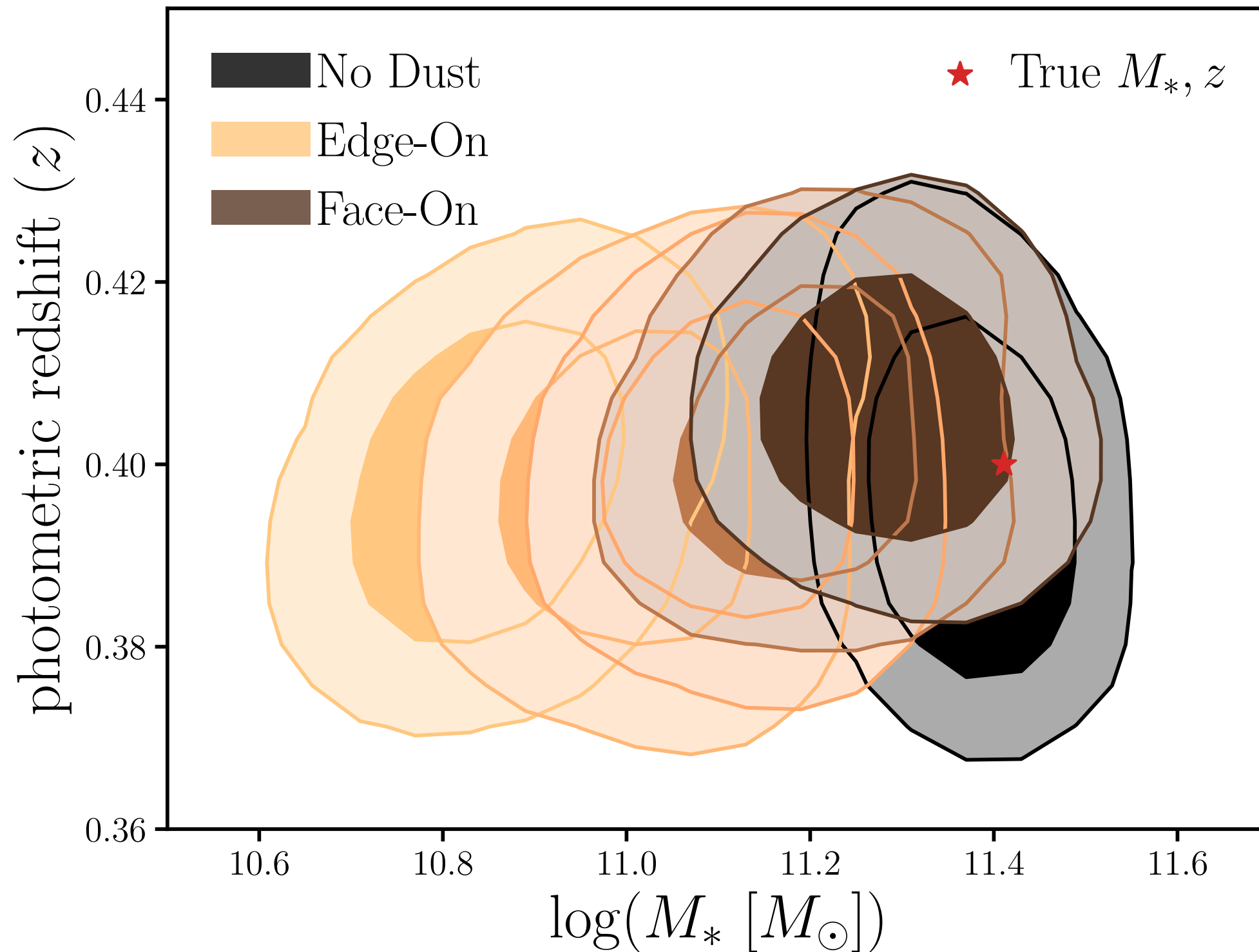
Galaxies Are Dusty...



Inhomogeneous Dust Biases



ChangHoon Hahn



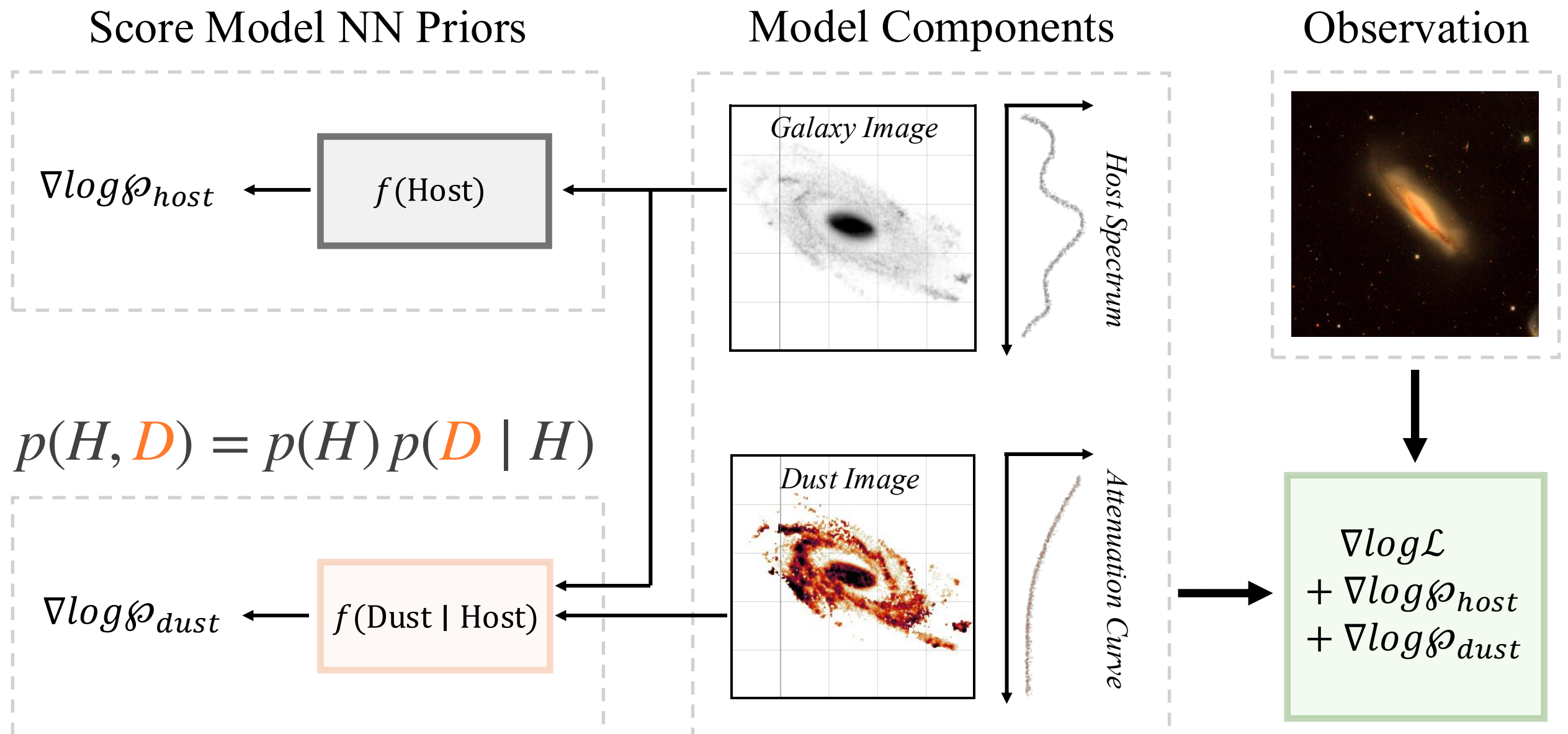
Hahn & Melchior (2025)
ApJ, 982, L44

Dust Modeling



Jared Siegel

$$(\text{Spectrum} \times \text{Morphology}) \odot e^{-\text{Spectrum}_{\text{Dust}} \times \text{Morphology}_{\text{Dust}}}$$



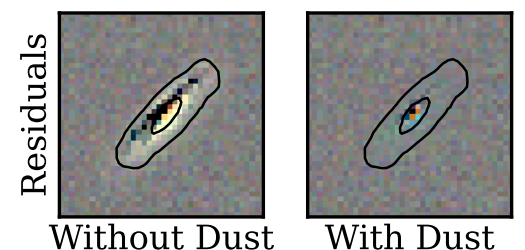
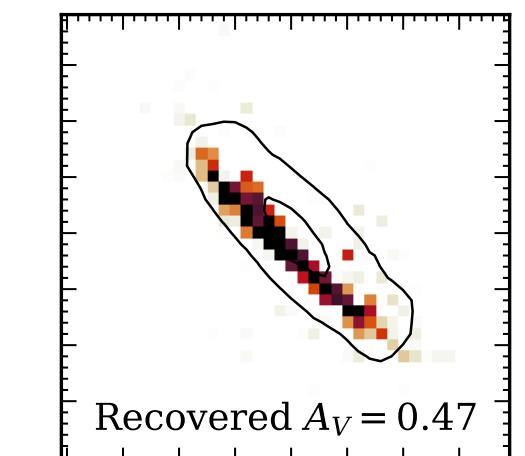
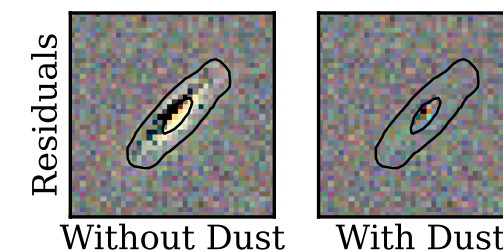
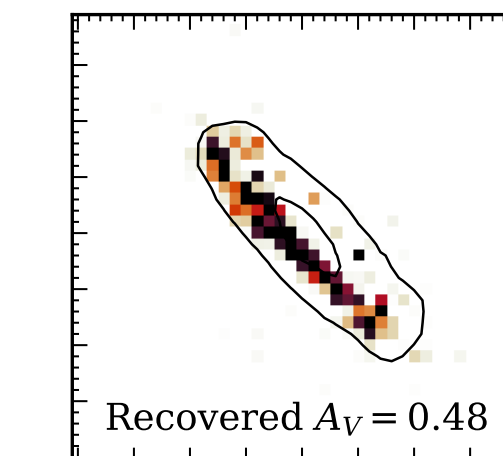
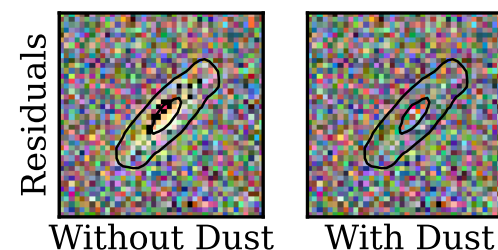
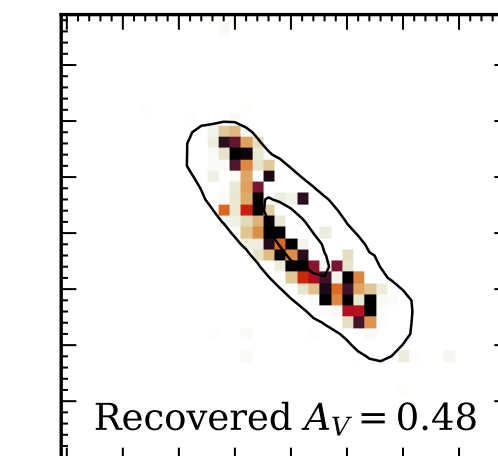
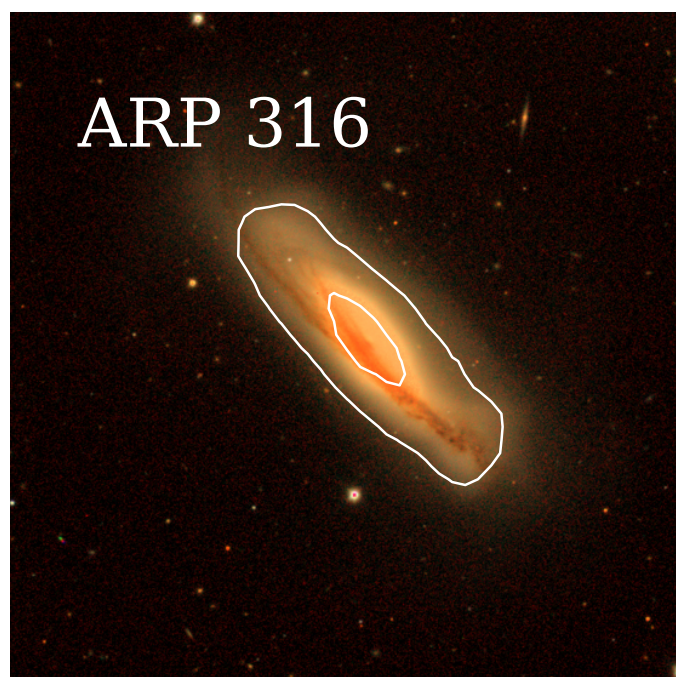
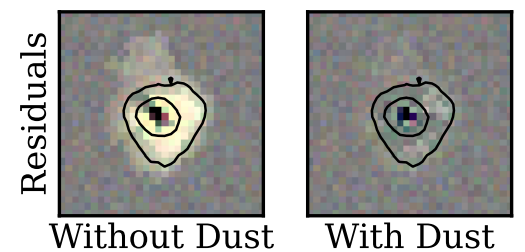
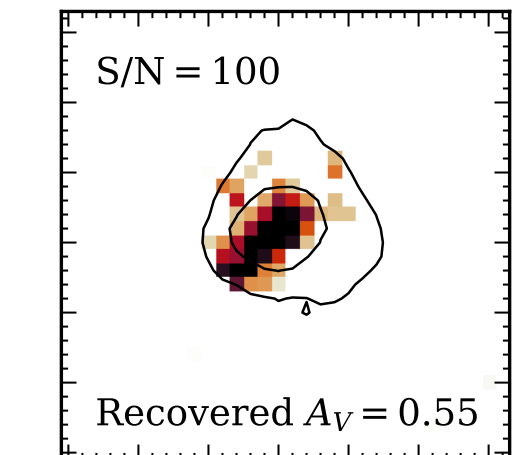
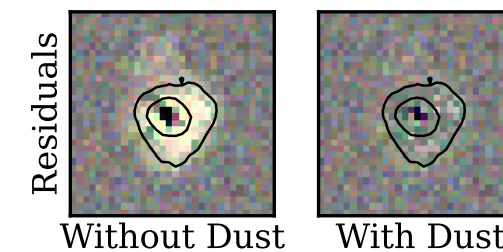
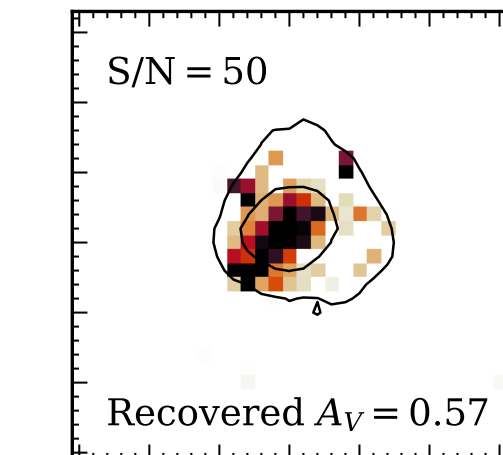
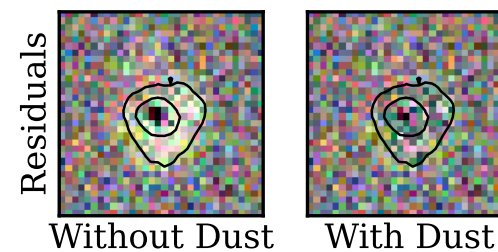
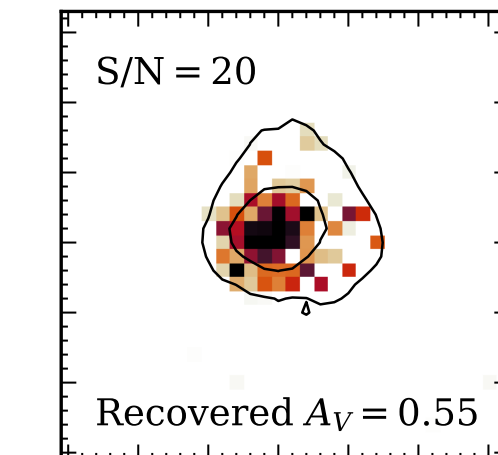
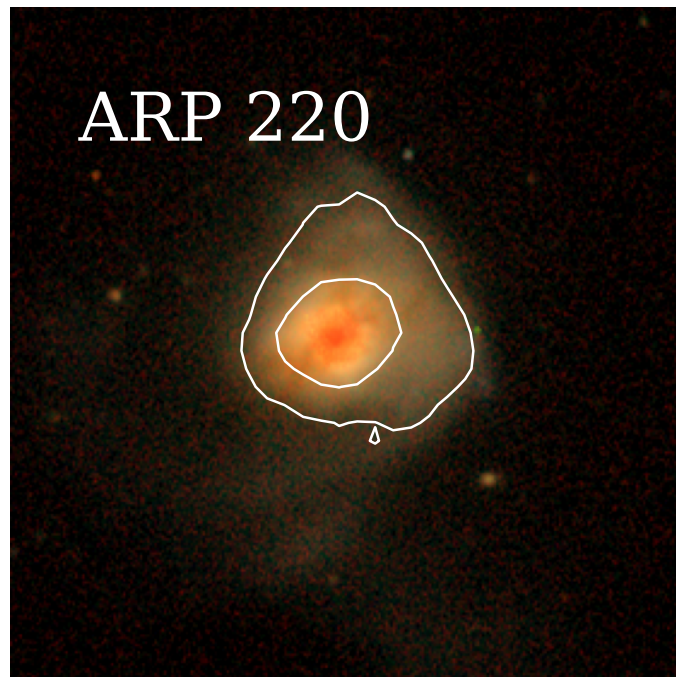
Dust Models for SDSS

Siegel & Melchior (2025)
ApJ, 986, 212

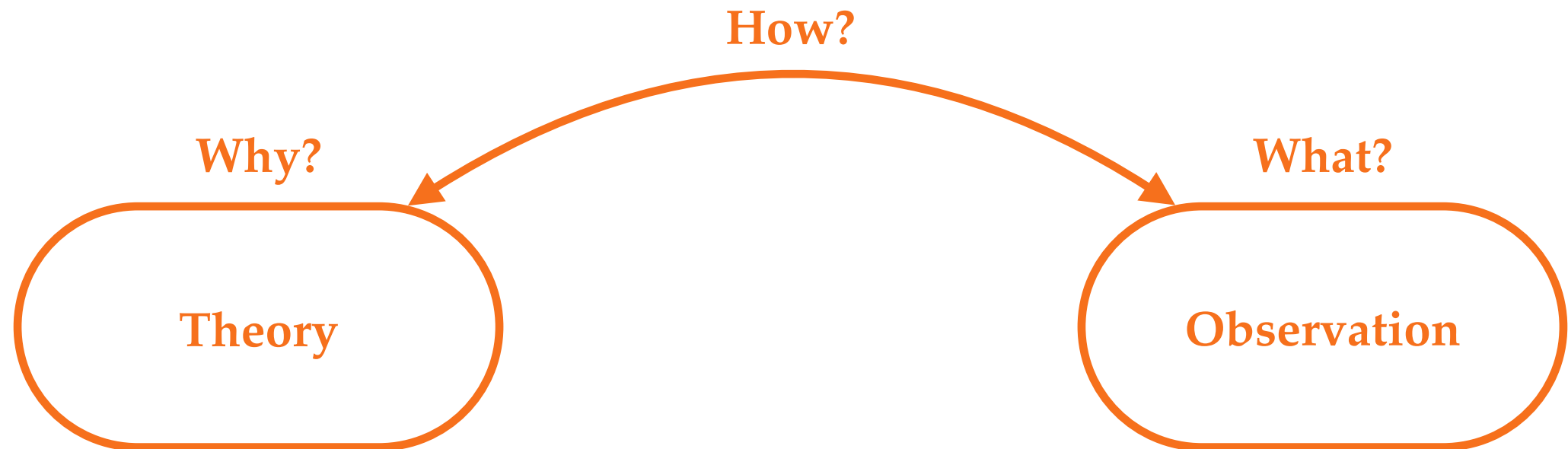
Low S/N



High S/N

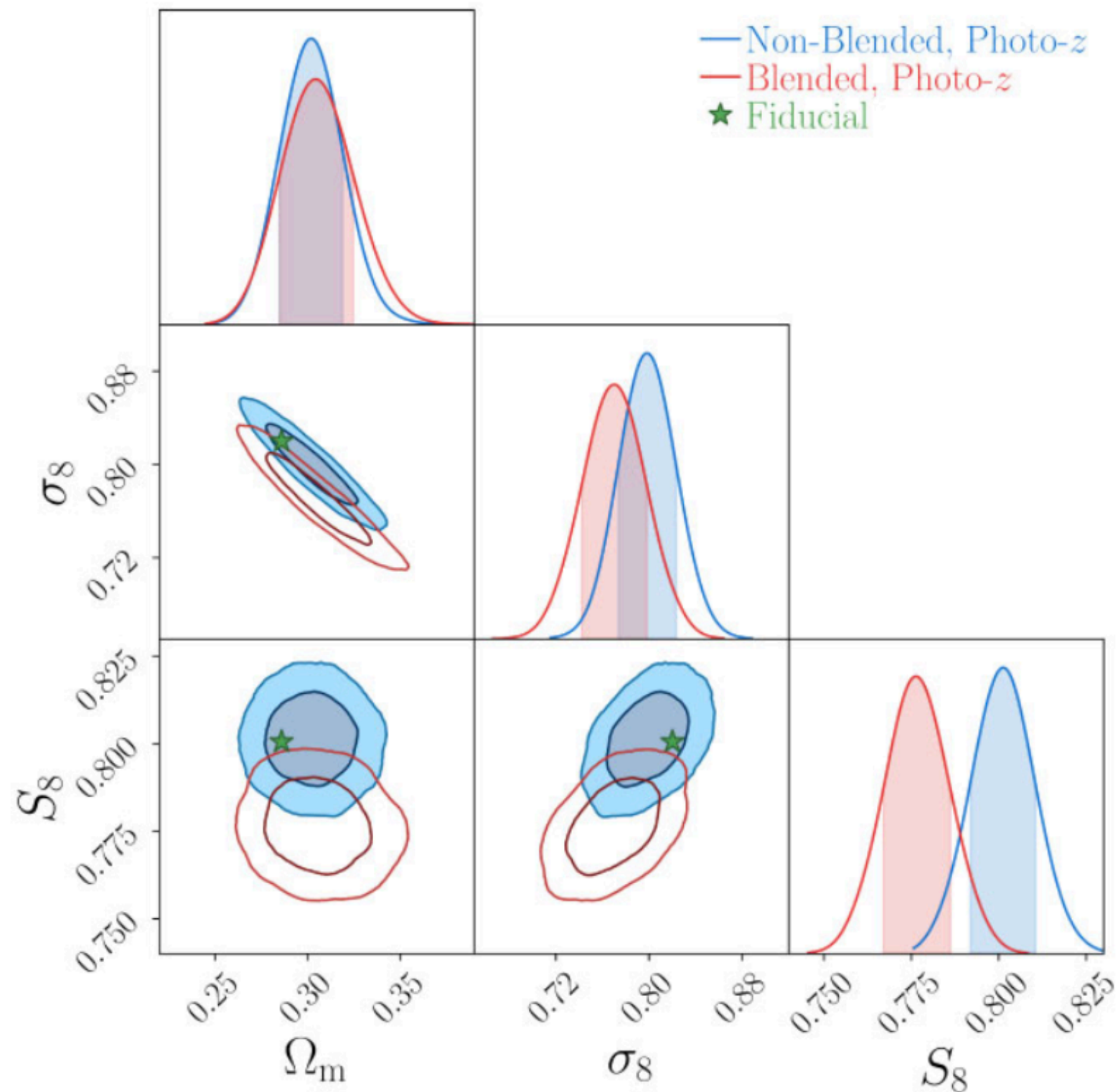


What Are Data Sciences?



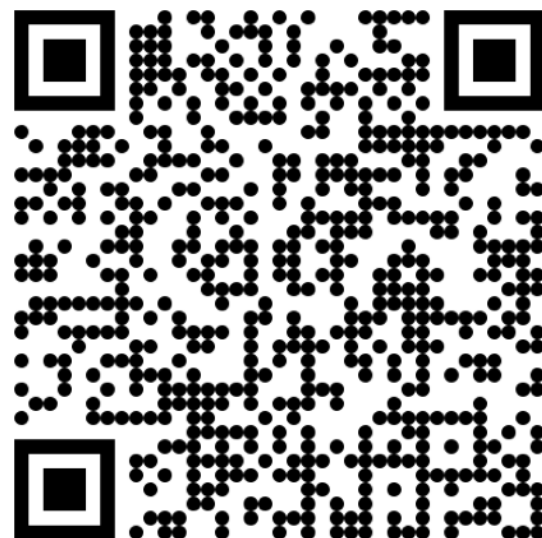
- ❖ Connection of theoretical questions and empirical answers
- ❖ Techniques from statistics, machine / deep learning, AI
- ❖ But also: information theory, linear algebra, optimization, numerical simulation, dynamical systems, control, ...

Do We Need Them?



The Problem with Astro Data Sciences

- ❖ Research on data science methods not in the physical sciences: requires LA, statistics, simulation, optimization, DL
- ❖ Interdisciplinary research (in academia) mostly a myth: Which discipline is responsible? AST, MAE, MAT, CS, STATS
- ❖ We have integrated other disciplines before: instrumentation, computational astrophysics
But it **requires effort & collaborative environment**
- ❖ Key driver now: AI



Astro Data Lab

Funding



ChangHoon Hahn



Charlotte Ward



Benjamin Remy



Christian Jespersen



Yan Liang



Jiaxuan Li



Matt Sampson



Jeff Shen



Jared Siegel


Schmidt Sciences



W. M. KECK
FOUNDATION

